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CONTENTS

The British Association for the Advancement of Science:—

Magnalia Naturæ; or, The Greater Problems of Biology: PROFESSOR D'ARCY WENTWORTH THOMPSON 417

Prospective Population of the United States: DR. W J MCGEE 428

The Silliman Lectures 435

Scientific Notes and News 435

University and Educational News 439

Discussion and Correspondence:—

A Carboniferous Flora in the Silurian: DAVID WHITE. *Professor Punnett's Error:* PROFESSOR F. C. NEWCOMBE. *Phenomena of Forked Lightning:* PROFESSOR FRANCIS E. NIPHER 440

Scientific Books:—

MacCurdy on Chiriquian Antiquities: PROFESSOR FRANZ BOAS. *Elsden's Chemical Geology:* PROFESSOR J. P. IDDINGS 442

The Relation between the Coloration and the Bathymetrical Distribution of the Cyclogasteridæ: DR. CHARLES V. BURKE 447

Special Articles:—

Isostasy, Oceanic Precipitation and the Formation of Mountain Systems: DR. P. G. NUTTING. *Musical Echoes:* DR. F. R. WATSON 453

Societies and Academies:—

The American Mathematical Society: PROFESSOR F. N. COLE 455

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THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

MAGNALIA NATURÆ; OR, THE GREATER PROBLEMS OF BIOLOGY[1]

THE science of zoology, all the more the incorporate science of biology, is no simple affair, and from its earliest beginnings it has been a great and complex and many-sided thing. We can scarce get a broader view of it than from Aristotle, for no man has ever looked upon our science with a more far-seeing and comprehending eye. Aristotle was all things that we mean by "naturalist" or "biologist." He was a student of the ways and doings of beast and bird and creeping thing; he was morphologist and embryologist; he had the keenest insight into physiological problems, though lacking that knowledge of the physical sciences without which physiology can go but a little way: he was the first and is the greatest of psychologists; and in the light of his genius biology merged in a great philosophy.

I do not for a moment suppose that the vast multitude of facts which Aristotle records were all, or even mostly, the fruit of his own immediate and independent observation. Before him were the Hippocratic and other schools of physicians and anatomists. Before him there were nameless and forgotten Fabres, Röesels, Réaumurs and Hubers, who observed the habits, the diet and the habitations of the sand-wasp or the mason-bee; who traced out the little lives, and discerned the vocal organs, of grasshopper and cicada; and who, together with generations of bee-keeping

[1] Address of the president to the Zoological Section. Portsmouth, 1911.

peasants, gathered up the lore and wisdom of the bee. There were fishermen skilled in all the cunning of their craft, who discussed the wanderings of tunny and mackerel, sword-fish or anchovy; who argued over the ages, the breeding-places and the food of this fish or that; who knew how the smooth dogfish breeds two thousand years before Johannes Müller; who saw how the male pipe-fish carries its young before Cavolini; and who had found the nest of the nest-building rock-fishes before Gerbe rediscovered it almost in our own day. There were curious students of the cuttle-fish (I sometimes imagine they may have been priests of that sea-born goddess to whom the creatures were sacred) who had diagnosed the species, recorded the habits and dissected the anatomy of the group, even to the discovery of that strange hectocotylus arm that baffled Della Chiaje, Cuvier and Koelliker, and that Verany and Heinrich Müller reexplained.

All this varied learning Aristotle gathered up and wove into his great web. But every here and there, in words that are unmistakably the master's own, we hear him speak of what are still the great problems and even the hidden mysteries of our science; of such things as the nature of variation, of the struggle for existence, of specific and generic differentiation of form, of the origin of the tissues, the problems of heredity, the mystery of sex, of the phenomena of reproduction and growth, the characteristics of habit, instinct and intelligence, and of the very meaning of life itself. Amid all the maze of concrete facts that century after century keeps adding to our store, these, and such as these, remain the great mysteries of natural science—the *Magnalia naturæ,* to borrow a great word from Bacon, who in his turn had borrowed it from St. Paul.

Not that these are the only great problems for the biologist, nor that there is even but a single class of great problems in biology. For Bacon himself speaks of the *magnalia naturæ, quoad usus humanos,* the study of which has for its objects "the prolongation of life or the retardation of age, the curing of diseases counted incurable, the mitigation of pain, the making of new species and transplanting of one species into another," and so on through many more. Assuredly I have no need to remind you that a great feature of this generation of ours has been the way in which biology has been justified of her children, in the work of those who have studied the *magnalia naturæ, quoad usus humanos.*

But so far are biologists from being nowadays engrossed in practical questions, in applied and technical zoology, to the neglect of its more recondite problems, that there never was a time when men thought more deeply or labored with greater zeal over the fundamental phenomena of living things; never a time when they reflected in a broader spirit over such questions as purposive adaptation, the harmonious working of the fabric of the body in relation to environment and the interplay of all the creatures that people the earth; over the problems of heredity and variation; over the mysteries of sex and the phenomena of generation and reproduction, by which phenomena, as the wise woman told, or reminded, Socrates, and as Harvey said again (and for that matter, as Coleridge said, and Weismann, but not quite so well) —by which, as the wise old woman said, we gain our glimpse of insight into eternity and immortality. These then, together with the problem of the origin of species, are indeed *magnalia naturæ;* and I take it that inquiry into these, deep and wide research specially directed to the solution of these, is characteristic of the spirit of our

time, and is the pass-word of the younger generation of biologists.

Interwoven with this high aim which is manifested in the biological work of recent years is another tendency. It is the desire to bring to bear upon our science, in greater measure than before, the methods and results of the other sciences, both those that in the hierarchy of knowledge are set above and below, and those that rank alongside of our own.

Before the great problems of which I have spoken, the cleft between zoology and botany fades away, for the same problems are common to the two sciences. When the zoologist becomes a student not of the dead but of the living, of the vital processes of the cell rather than of the dry bones of the body, he becomes once more a physiologist, and the gulf between these two disciplines disappears. When he becomes a physiologist, he becomes, *ipso facto,* a student of chemistry and of physics. Even mathematics has been pressed into the service of the biologist, and the calculus of probabilities is not the only branch of mathematics to which he may usefully appeal.

The physiologist has long had as his distinguishing characteristic, giving his craft a rank superior to the sister branch of morphology, the fact that in his great field of work, and in all the routine of his experimental research, the methods of the physicist and the chemist, the lessons of the anatomist, and the experience of the physician are inextricably blended in one common central field of investigation and thought. But it is much more recently that the morphologist and embryologist have made use of the method of experiment, and of the aid of the physical and chemical sciences—even of the teachings of philosophy: all in order to probe into properties of the living organism that men were wont to take for granted, or to regard as beyond their reach, under a narrower interpretation of the business of the biologist. Driesch and Loeb and Roux are three among many men who have become eminent in this way in recent years, and their work we may take as typical of methods and aims such as those of which I speak. Driesch, both by careful experiment and by philosophic insight, Loeb, by his conception of the dynamics of the cell and by his marvellous demonstrations of chemical and mechanical fertilization, Roux, with his theory of auto-determination, and by all the labors of the school of *Entwickelungsmechanik* which he has founded, have all in various ways, and from more or less different points of view, helped to reconstruct and readjust our ideas of the relations of embryological processes, and hence of the phenomenon of life itself, on the one hand to physical causes (whether external to or latent in the mechanism of the cell), or on the other to the ancient conception of a vital element alien to the province of the physicist.

No small number of theories or hypotheses, that seemed for a time to have been established on ground as firm as that on which we tread, have been reopened in our day. The adequacy of natural selection to explain the whole of organic evolution has been assailed on many sides; the old fundamental subject of embryological debate between the evolutionists or preformationists (of the school of Malpighi, Haller and Bonnet) and the advocates of epigenesis (the followers of Aristotle, of Harvey, of Caspar F. Wolff and of Von Baer) is now discussed again, in altered language, but as a pressing question of the hour; the very foundations of the cell-theory have been scrutinized to decide, for instance, whether the segmented ovum, or even the complete organism, be a colony of quasi-independent cells, or a living unit in which cell differ-

entiation is little more than a superficial phenomenon; the whole meaning, bearing and philosophy of evolution has been discussed by Bergson, on a plane to which neither Darwin nor Spencer ever attained; and the hypothesis of a vital principle, or vital element, that had lain in the background for near a hundred years, has come into men's mouths as a very real and urgent question, the greatest question for the biologist of all.

In all ages the mystery of organic form, the mystery of growth and reproduction, the mystery of thought and consciousness, the whole mystery of the complex phenomena of life, have seemed to the vast majority of men to call for description and explanation in terms alien to the language which we apply to inanimate things; though at all times there have been a few who sought, with the materialism of Democritus, Lucretius or Giordano Bruno, to attribute most, or even all, of these phenomena to the category of physical causation.

For the first scientific exposition of vitalism, we must go back to Aristotle, and to his doctrine of the three parts of the tripartite soul: according to which doctrine, in Milton's language, created things "by grandual change sublimed, To vital spirits aspire, to animal, To intellectual!" The first and lowest of these three, the ψυχὴ ἡ θρεπτική, by whose agency nutrition is effected, is ἡ πρώτη ψυχή, the inseparable concomitant of life itself. It is inherent in the plant as well as in the animal and in the Linnean aphorism, *Vegetabilia crescunt et vivunt,* its existence is admitted in a word. Under other aspects, it is all but identical with the ψυχὴ αὐξητική and γεννητική the soul of growth and of reproduction: and in this composite sense it is no other than Driesch's "Entelechy," the hypothetic natural agency that presides over the form and formation of the body. Just as Driesch's psychoid or psychoids, which are the basis of instinctive phenomena, of sensation, instinct, thought, reason, and all that directs that body which entelechy has formed, are no other than the αἰσθητική, whereby *animalia vivunt et sentiunt,* and the διανοητική to which Aristotle ascribes the reasoning faculty of man. Save only that Driesch like Darwin, would deny the restriction of νοῦς, or reasoning, to man alone, and would extend it to animals, it is clear, and Driesch himself admits,[2] that he accepts both the vitalism and the analysis of vitalism laid down by Aristotle.

The πνεῦμα of Galen, the *vis plastica,* the *vis vitæ formatrix,* of the older physiologist, the *Bildungstrieb* of Blumenbach, the *Lebenskraft* of Paracelsus, Stahl and Treviranus, "shaping the physical forces of the body to its own ends," "dreaming dimly in the grain of the promise of the full corn in the ear,"[3] these and many more, like Driesch's "entelechy" of to-day, are all conceptions under which successive generations strive to depict the something that separates the earthy from the living, the living from the dead. And John Hunter described his conception of it in words not very differentt from Driesch's, when he said that his principle, or agent, was independent of organization, which yet it animates, sustains and repairs; it was the same as Johannes Müller's conception of an innate "unconscious idea."

Even in the middle ages, long before

[2] "Science and Philosophy of the Organism" (Gifford Lectures), II., p. 83, 1908.

[3] *Cit.* Jenkinson (Art. "Vitalism," in *Hibbert Journal,* April, 1911), who has given me the following quotation: "Das Weizenkorn hat allerdings Bewusstsein dessen was in ihm ist und aus ihm werden kann, und traümt wirklich davon. Sein Bewusstsein und seine Träume mögen dunkel genung sein"; Treviranus, "Erscheinungen und Gesetze des organischen Lebens," 1831.

Descartes, we can trace, if we interpret the language and the spirt of the time, an antithesis that, if not identical, is at least parallel to our alternative between vitalistic and mechanical hypotheses. For instance, Father Harper tells us that Suarez maintained, in opposition to St. Thomas, that in generation and development a divine interference is postulated, by reason of the perfection of living beings; in opposition to St. Thomas, who (while invariably making an exception in the case of the human soul) urged that, since the existence of bodily and natural forms consists solely in their union with matter, the ordinary agencies which operate on matter sufficiently account for them.[4]

But in the history of modern science, or of modern physiology, it is of course to Descartes that we trace the origin of our mechanical hypotheses—to Descartes, who, imitating Archimedes, said, "Give me matter and motion, and I will construct the universe." In fact, leaving the more shadowy past alone, we may say that it is since Descartes watched the fountains in the garden, and saw the likeness between their machinery of pumps and pipes and reservoirs to the organs of the circulation of the blood, and since Vaucanson's marvelous automata lent plausibility to the idea of a "living automaton," it is since then that men's minds have been perpetually swayed by one or other of the two conflicting tendencies, either to seek an explanation of the phenomena of living things in physical and mechanical considerations, or to attribute them to unknown and mysterious causes, alien to physics and peculiarly concomitant with life. And some men's temperaments, training, and even avocations, render them more prone to the one side of this unending controvery, as the minds of other men are naturally more open to the other. As Kühne said a few years ago at Cambridge, the physiologists have been found for several generations leaning on the whole to the mechanical or physico-chemical hypothesis, while the zoologists have been very generally on the side of the vitalists.

The very fact that the physiologists were trained in the school of physics, and the fact that the zoologists and botanists relied for so many years upon the vague undefined force of "heredity" as sufficiently accounting for the development of the organism, an intrinsic force whose results could be studied but whose nature seemed remote from possible analysis or explanation, these facts alone go far to illustrate and to justify what Kühne said.

Claude Bernard held that mechanical, physical and chemical forces summed up all with which the physiologist has to deal. Verworn defined physiology as "the chemistry of the proteids"; and I think that another physiologist (but I forget who) has declared that the mystery of life lay hidden in "the chemistry of the enzymes." But of late, as Dr. Haldane showed in his address a couple of years ago to the Physiological Section, it is among the physiologists themselves, together with the embryologists, that we find the strongest indications of a desire to pass beyond the horizon of Descartes, and to avow that physical and chemical methods, the methods of Helmholtz, Ludwig and Claude Bernard, fall short of solving the secrets of physiology. On the other hand, in zoology, resort to the

[4] "Cum formarum naturalium et corporalium esse non consistat nisi in unione ad materiam; ejusdem agentis esse videtur eas producere, cujus est materiam transmutare. Secundo, quia cum hujusmodi formæ non excedant virtutem et ordinem et facultatem principiorum agentium in natura, nulla videtur necessitas eorum originem in principia reducere altiora."—Aquinas, "De Pot.," Q. III., *a*, 11; Cf. Harper, "Metaphysics of the School," III., 1, p. 152.

method of experiment, the discovery, for instance, of the wonderful effects of chemical or even mechanical stimulation in starting the development of the egg, and again the ceaseless search into the minute structure, or so-called mechanism, of the cell, these, I think, have rather tended to sway a certain number of zoologists in the direction of the mechanical hypothesis.

But on the whole, I think it is very manifest that there is abroad on all sides a greater spirit of hesitation and caution than of old, and that the lessons of the philosopher have had their influence on our minds. We realize that the problem of development is far harder than we had begun to let ourselves suppose: that the problems of organogeny and phylogeny (as well as those of physiology) are not comparatively simple and well-nigh solved, but are of the most formidable complexity. And we would, most of us, confess, with the learned author of "The Cell in Development and Inheritance," "that we are utterly ignorant of the manner in which the substance of the germ-cell can so respond to the influence of the environment as to call forth an adaptive variation; and again, that the gulf between the lowest forms of life and the inorganic world is as wide as, if not wider than, it seemed a couple of generations ago."[5]

While we keep an open mind on this question of vitalism, or while we lean as so many of us now do, or or even cling with a great yearning, to the belief that something other than the physical forces animates and sustains the dust of which we are made, it is rather the business of the philosopher than of the biologist, or of the biologist only when he has served his humble and severe apprenticeship to philosophy, to deal with the ultimate problem. It is the plain bounden duty of the biologist to pursue his course, unprejudiced by vitalistic hypotheses, along the road of observation and experiment, according to the accepted discipline of the natural and physical sciences; indeed, I might perhaps better say the physical sciences alone, for it is already a breach of their discipline to invoke, until we feel we absolutely must, that shadowy force of "heredity," to which, as I have already said, biologists have been accustomed to ascribe so much. In other words, it is an elementary scientific duty, it is a rule that Kant himself laid down,[6] that we should explain, just as far as we possibly can, all that is capable of such explanation, in the light of the properties of matter and of the forms of energy with which we are already acquainted.

It is of the essence of physiological science to investigate the manifestations of energy in the body, and to refer them, for instance, to the domains of heat, electricity or chemical activity. By this means a vast number of phenomena, of chemical and other actions of the body, have been relegated to the domain of physical science and withdrawn from the mystery that still attends on life: and by this means, continued for generations, the physiologists, or certain of them, now tell us that we begin again to descry the limitations of physical inquiry, and the region where a very different hypothesis insists on thrusting itself in. But the morphologist has not gone nearly so far as the physiologist in the use of physical methods. He sees so great a gulf between the crystal and the cell, that the very fact of the physicist and the mathematician being able to explain the form of the one, by simple laws of spatial arrangement where molecule fits into molecule, seems to deter, rather than to attract, the biologist from attempting to explain organic forms by mathematical or physical

[5] Wilson, *op. cit.*, 1906, p. 434.

[6] In his "Critique of Teleological Judgment."

law. Just as the embryologist used to explain everything by heredity, so the morphologist is still inclined to say, "the thing is alive, its form is an attribute of itself, and the physical forces do not apply." If he does not go so far as this, he is still apt to take it for granted that the physical forces can only to a small and even insignificant extent blend with the intrinsic organic forces in producing the resultant form. Herein lies our question in a nutshell. Has the morphologist yet sufficiently studied the forms, external and internal, of organisms, in the light of the properties of matter, of the energies that are associated with it, and of the forces by which the actions of these energies may be interpreted and described? Has the biologist, in short, fully recognized that there is a borderland not only between physiology and physics, but between morphology and physics, and that the physicist may, and must, be his guide and teacher in many matters regarding organic form?

Now this is by no means a new subject, for such men as Berthold and Errera, Rhumbler and Dreyer, Bütschli and Verworn, Driesch and Roux, have already dealt or deal with it. But on the whole it seems to me that the subject has attracted too little attention, and that it is well worth our while to think of it to-day.

The first point, then, that I wish to make in this connection is, that the form of any portion of matter, whether it be living or dead, its form and the changes of form that are apparent in its movements and in its growth, may in all cases alike be described as due to the action of force. In short, the form of an object is a "diagram of forces"—in this sense at least, that from it we can judge of or deduce the forces that are acting or have acted upon it; in this strict and particular sense, it is a diagram: in the case of a solid, of the forces that *have* been impressed upon it when its conformation was produced, together with those that enable it to retain its conformation; in the case of a liquid (or of a gas), of the forces that are for the moment acting on it to restrain or balance its own inherent mobility. In an organism, great or small, it is not merely the nature of the *motions* of the living substance that we must interpret in terms of force (according to kinetics), but also the *conformation* of the organism itself, whose permanence or equilibrium is explained by the interaction or balance of forces, as described in statics.

If we look at the living cell of an *Amœba* or a *Spirogyra,* we see a something which exhibits certain active movements, and a certain fluctuating, or more or less lasting, form; and its form at a given moment, just like its motions, is to be investigated by the help of physical methods, and explained by the invocation of the mathematical conception of force.

Now the state, including the shape or form, of a portion of matter is the resultant of a number of forces, which represent or symbolize the manifestations of various kinds of energy; and it is obvious, accordingly, that a great part of physical science must be understood or taken for granted as the necessary preliminary to the discussion on which we are engaged.

I am not going to attempt to deal with, or even to enumerate, all the physical forces or the properties of matter with which the pursuit of this subject would oblige us to deal—with gravity, pressure, cohesion, friction, viscosity, elasticity, diffusion and all the rest of the physical factors that have a bearing on our problem. I propose only to take one or two illustrations from the subject of *surface-tension,* which subject has already so largely engaged the attention of the physiologists. Nor will I even attempt to sketch the gen-

eral nature of this phenomenon, but will only state (as I fear for my purpose I must) a few of its physical manifestations or laws. Of these the most esential facts for us are as follows: Surface-tension is manifested only in fluid or semi-fluid bodies, only at the surface of these: though we may have to interpret surface in a liberal sense in cases where the interior of the mass is other than homogeneous. Secondly, a fluid may, according to the nature of the substance with which it is in contact, or (more strictly speaking) according to the distribution of energy in the system to which it belongs, tend either to spread itself out in a film, or, conversely, to contract into a drop, striving in the latter case to reduce its surface to a minimal area. Thirdly, when three substances are in contact (and subject to surface-tension), as when water surrounds a drop of protoplasm in contact with a solid, then at any and every point of contact, certain definite angles of equilibrium are set up and maintained between the three bodies, which angles are proportionate to the magnitudes of the surface-tensions existing between the three. Fourthly, a fluid film can only remain in equilibrium when its curvature is everywhere constant. Fifthly, the only surfaces of revolution which meet this condition are six in number, of which the plane, the sphere, the cylinder and the so-called unduloid and catenoid are the most important. Sixthly, the cylinder can not remain in free equilibrium if prolonged beyond a length equal to its own circumference, but, passing through the unduloid, tends to break up into spheres: though this limitation may be counteracted or relaxed, for instance, by viscosity. Finally, we have the curious fact that, in a complex system of films, such as a homogeneous froth of bubbles, three partition-walls and no more always meet at a crest, at equal angles, as, for instance, in the very simple case of a layer of uniform hexagonal cells; and (in a solid system) the crests, which may be straight or curved, always meet, also at equal angles, four by four, in a common point. From these physical facts, or laws, the morphologist, as well as the physiologist, may draw important consequences.

It was Hofmeister who first showed, more than forty years ago, that when any drop of protoplasm, either over all its surface or at some free end (as at the tip of the pseudopodium of an *Amœba*), is seen to "round itself off," that is not the effect of physiological or vital contractility, but is a simple consequence of surface-tension—of the law of the minimal surface; and in the physiological side, Engelmann, Bütschli and others have gone far in their development of the idea.

It was Plateau, I think, who first showed that the myriad sticky drops or beads upon the weft of a spider's web, their form, their size, their distance apart, and the presence of the tiny intermediate drops between, were in every detail explicable as the result of surface-tension, through the law of minimal surface and through the corollary to it which defines the limits of stability of the cylinder; and, accordingly, that with their production, the will or effort or intelligence of the spider had nothing to do. The beaded form of a long, thin pseudopodium, for instance of a Heliozoan, is an identical phenomenon.

It was Errera who first conceived the idea that not only the naked surface of the cell but the contiguous surfaces of two naked cells, or the delicate incipient cell-membrane or cell-wall between, might be regarded as a weightless film, whose position and form were assumed in obedience to surface-tension. And it was he who first showed that the symmetrical forms of the unicellular and simple multicellular organ-

isms, up to the point where the development of a skeleton complicates the case, were one and all identical with the plane, sphere, cylinder, unduloid and catenoid, or with combinations of these.

It was Berthold and Errera who, almost simultaneously, showed (the former in far the greater detail) that in a plant each new cell-partition follows the law of minimal surface, and tends (according to another law which I have not particularized) to set itself at right angles to the preceding solidified wall: so giving a simple and adequate physical explanation of what Sachs had stated as an empirical morphological rule. And Berthold further showed how, when the cell-partition was curved, its precise curvature as well as its position was in accordance with physical law.

There are a vast number of other things that we can satisfactorily explain on the same principle and by the same laws. The beautiful catenary curve of the edge of the pseudopodium, as it creeps up its axial rod in a Heliozoan or a Radiolarian, the hexagonal mesh of bubbles, or vacuoles, on the surface of the same creatures, the form of the little groove that runs round the waist of a Peridinian, even (as I believe) the existence, form and undulatory movements of the undulatory membrane of a Trypanosome, or of that around the tail of the spermatozoon of a newt—every one of these, I declare, is a case where the resultant form can be well explained by, and can not possibly be understood without, the phenomenon of surface-tension: indeed, in many of the simpler case the facts are so well explained by surface-tension that it is difficult to find place for a conflicting, much less an overriding, force.

I believe, for my own part, that even the beautiful and varied forms of the Foraminifera may be ascribed to the same cause; but here the problem is just a little more complex, by reason of the successive consolidations of the shell. Suppose the first cell or chamber to be formed, assuming its globular shape in obedience to our law, and then to secrete its calcareous envelope. The new growing bud of protoplasm, accumulating outside the shell, will, in strict accordance with the surface-tensions concerned, either fail to "wet" or to adhere to the first-formed shell, and will so detach itself as a unicellular individual (*Orbulina*); or else it will flow over a less or greater part of the original shell, until its free surface meets it at the required angle of equilibrium. Then, according to this angle, the second chamber may happen to be all but detached (*Globigerina*), or, with all intermediate degrees, may very nearly wholly enwrap the first. Take any specific angle of contact, and presume the same conditions to be maintained, and therefore the same angle to be repeated, as each successive chamber follows on the one before; and you will thereby build up regular forms, spiral or alternate, that correspond with marvelous accuracy to the actual forms of the Foraminifera. And this case is all the more interesting because the allied and successive forms so obtained differ only in degree, in the magnitude of a single physical or mathematical factor; in other words, we get not only individual phenomena, but lines of apparent *orthogenesis*, that seem explicable by physical laws, and attributable to the continuity between successive states in the continuous or gradual variation of a physical condition. The resemblance between allied and related forms, as Hartmann demonstrated and Giard admitted years ago, is not always, however often, to be explained by common descent and parentage.[7]

In the segmenting egg we have the sim-

[7] Cf. Giard, "Discours inaugurale," *Bull. Scientif.* (3), 1, 1888.

pler phenomenon of a "laminar system," uncomplicated by the presence of a solid framework; and here, in the earliest stages of segmentation, it is easy to see the correspondence of the planes of division with what the laws of surface-tension demand. For instance, it is not the case (though the elementary books often represent it so) that when the totally segmenting egg has divided into four segments, the four partition walls ever remain in contact at a single point; the arrangement would be unstable, and the position untenable. But the laws of surface-tension are at once seen to be obeyed, when we recognize the little *cross-furrow* that separates the blastomeres, two and two, leaving in each case three only to meet at a point in our diagram, which point is in reality a section of a ridge or crest.

Very few have tried, and one or two (I know) have tried and not succeeded, to trace the action and the effects of surface-tension in the case of a highly complicated, multi-segemented egg. But it is not surprising if the difficulties which such a case presents appear to be formidable. Even the conformation of the interior of a soap-froth, though absolutely conditioned by surface-tension, presents great difficulties, and it was only in the last years of Lord Kelvin's life that he showed all previous workers to have been in error regarding the form of the interior cells.

But what, for us, does all this amount to? It at least suggests the possibility of so far supporting the observed facts of organic form on mathematical principles, as to bring morphology within or very near to Kant's demand that a true natural science should be justified by its relation to mathematics.[8] But if we were to carry these principles further and to succeed in proving them applicable in detail, even to the showing that the manifold segmentation of the egg was but an exquisite froth, would it wholly revolutionize our biological ideas? It would greatly modify some of them, and some of the most cherished ideas of the majority of embryologists; but I think that the way is already paved for some such modification. When Loeb and others have shown us that half, or even a small portion of an egg, or a single one of its many blastomeres, can give rise to an entire embryo, and that in some cases *any* part of the ovum can originate *any* part of the organism, surely our eyes are turned to the *energies* inherent in the matter of the egg (not to speak of a presiding entelechy), and away from its original formal operations of division. Sedgwick has told us for many years that we look too much to the individuality of the individual cell, and that the organism, at least in the embryonic body, is a continuous syncytium. Hofmeister and Sachs have repeatedly told us that in the plant, the growth of the mass, the growth of the organ, is the primary fact; and De Bary has summed up the matter in his aphorism, "Die Pflanze bildet Zellen, nicht die Zelle bildet Pflanzen." And in many other ways, as many of you are well aware, the extreme position of the cell-theory, that the cells are the ultimate individuals and that the organism is but a colony of quasi-independent cells, has of late years been called in question.

There are no problems connected with morphology that appeal so closely to my mind, or to my temperament, as those that are related to mechanical considerations, to mathematical laws, or to physical and chemical processes.

I love to think of the logarithmic spiral

[8] "Ich behaupte aber dass in jeder besonderen Naturlehre nur so viel *eigentliche* Wissenschaft angetroffen werden könne, als darin Mathematik anzutreffen ist."—Kant, in preface to "Metaphys. Anfangsgründe der Naturwissenschaft" (Werke, ed. Hartenstein, Vol. IV., p. 360).

that is engraven over the grave of that great anatomist, John Goodsir (as it was over that of the greatest of the Bernouillis), so graven because it interprets the form of every molluscan shell, of tusk and horn and claw and many another organic form besides. I like to dwell upon those lines of mechanical stress and strain in a bone that give it its strength where strength is required, that Hermann Meyer and J. Wolff described, and on which Roux has bestowed some of his most thoughtful work; or on the "stream-lines" in the bodily form of fish or bird, from which the naval architect and the aviator have learned so much. I admire that old paper of Peter Harting's in which he paved the way for investigation of the origin of spicules, and of all the questions of crystallization or pseudo-crystallization in presence of colloids, on which subject Lehmann has written his recent and beautiful book. I sympathize with the efforts of Henking, Rhumbler, Hartog, Gallardo, Leduc and others to explain on physical lines the phenomena of nuclear division. And, as I have said to-day, I believe that the forces of surface-tension, elasticity and pressure are adequate to account for a great multitude of the simpler phenomena, and the permutations and combinations thereof, that are illustrated in organic form.

I should gladly and easily have spent all my time this morning in dealing with these questions alone. But I was loath to do so, lest I should seem to overrate their importance, and to appear to you as an advocate of a purely mechanical biology.

I believe all these phenomena to have been unduly neglected, and to call for more attention than they have received. But I know well that though we push such explanations to the uttermost, and learn much in the so doing, they will not touch the heart of the great problems that lie deeper than the physical plane. Over the ultimate problems and causes of vitality, over what is implied in the organization of the living organism, we shall be left wondering still.

To a man of letters and the world like Addison, it came as a sort of revelation that light and color were not objective things but subjective, and that back of them lay only motion or vibration, some simple activity. And when he wrote his essay on these startling discoveries, he found for it, from Ovid, a motto well worth bearing in mind, *causa latet, vis est notissima.* We may with advantage recollect it, when we seek and find the force that produces a direct effect, but stand in utter perplexity before the manifold and transcendent meanings of that great word "cause."

The similarity between organic forms and those that physical agencies are competent to produce still leads some men, such as Stéphane Leduc, to doubt or to deny that there is any gulf between, and to hold that spontaneous generation or the artificial creation of the living is but a footstep away. Others, like Delage and many more, see in the contents of the cell only a complicated chemistry, and in variation only a change in the nature and arrangement of the chemical constituents; they either cling to a belief in "heredity," or (like Delage himself) replace it more or less completely by the effects of functional use and by chemical stimulation from without and from within. Yet others, like Felix Auerbach, still holding to a physical or quasi-physical theory of life, believe that in the living body the dissipation of energy is controlled by a guiding principle, as though by Clerk Maxwell's demons; that for the living the law of entropy is thereby reversed; and that life itself is that which has been evolved to counteract and battle

with the dissipation of energy. Berthold, who first demonstrated the obedience to physical laws in the fundamental phenomena of the dividing cell or segmenting egg, recognizes, almost in the words of John Hunter, a quality in the living protoplasm, *sui generis,* whereby its maintenance, increase and reproduction are achieved. Driesch, who began as a "mechanist," now, as we have seen, harks back straight to Aristotle, to a twin or triple doctrine of the soul. And Bergson, rising into heights of metaphysics where the biologist, *quâ* biologist, can not climb, tells us (like Duran) that life transcends teleology, that the conceptions of mechanism and finality fail to satisfy, and that only "in the absolute do we live and move and have our being."

We end but a little way from where we began.

With all the growth of knowledge, with all the help of all the sciences impinging on our own, it is yet manifest, I think, that the biologists of to-day are in no self-satisfied and exultant mood. The reasons and the reasoning that contented a past generation call for reinquiry, and out of the old solutions new questions emerge; and the ultimate problems are as inscrutable as of old. That which, above all things, we would explain baffles explanation; and that the living organism is a living organism tends to reassert itself as the biologist's fundamental conception and fact. Nor will even this concept serve us and suffice us when we approach the problems of consciousness and intelligence and the mystery of the reasoning soul; for these things are not for the biologist at all, but constitute the psychologist's scientific domain.

In wonderment, says Aristotle, does philosophy begin,[9] and more than once he rings the changes on the theme. Now, as in the beginning, wonderment and admiration are the portion of the biologist, as of all those who contemplate the heavens and the earth, the sea, and all that in them is.

And if wonderment springs, as again Aristotle tells us, from ignorance of the causes of things, it does not cease when we have traced and discovered the proximate causes, the physical causes, the efficient causes of our phenomena. For beyond and remote from physical causation lies the end, the final cause of the philosopher, the reason why, in the which are hidden the problems of organic harmony and autonomy and the mysteries of apparent purpose, adaptation, fitness and design. Here, in the region of teleology, the plain rationalism that guided us through the physical facts and causes begins to disappoint us, and intuition, which is of close kin to faith, begins to make herself heard.

And so it is that, as in wonderment does all philosophy begin, so in amazement does Plato tell us that all our philosophy comes to an end.[10] Ever and anon, in presence of the *magnalia naturæ,* we feel inclined to say with the poet:

οὐ γάρ τι νῦν γε κἀχθὲς, ἀλλ' ἀεί ποτε
ζῇ ταῦτα κοὐδεὶς οἶδεν ἐξ ὅτου 'φάνη.

"These things are not of to-day nor yesterday, but evermore, and no man knoweth whence they came."

I will not quote the noblest words of all that come into my mind; but only the lesser language of another of the greatest of the Greeks: "The ways of His thoughts are as paths in a wood thick with leaves, and one seeth through them but a little way."

D'Arcy Wentworth Thompson

PROSPECTIVE POPULATION OF THE UNITED STATES

Various estimates of the probable or possible future population of the United States

[9] "Met.," I., 2, 982*b*, 12, etc.

[10] Cf. Coleridge, "Biogr. Lit."